

Proceedings of the PIC 2012, Štrbské Pleso, Slovakia

CHARGED-PARTICLE VETO DETECTOR FOR THE $K_L \rightarrow \pi^0 \nu \bar{\nu}$ STUDY IN THE J-PARC K^OTO EXPERIMENT

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A charged-particle veto detector was constructed to study the rare decay $K_L \rightarrow \pi^0 \nu \bar{\nu}$ in the J-PARC K^OTO experiment. This detector consists of 3mm-thick plastic scintillator strips and wavelength shifting fibers coupled with MPPCs at the both ends, which makes it possible to obtain large light output over the wide region. After the construction and installation to the K^OTO experimental area, its performance was studied using charged particles from K_L decays. As a preliminary result, we found that the detector had the light yield larger than 10p.e./100keV and the timing resolution better than 3ns for most regions, which satisfied the requirements to achieve the standard model sensitivity ($\sim 10^{-11}$) for the $K_L \rightarrow \pi^0 \nu \bar{\nu}$ detection.

1 K^OTO experiment for $K_L \rightarrow \pi^0 \nu \bar{\nu}$

The decay $K_L \rightarrow \pi^0 \nu \bar{\nu}$ is a CP-violating flavor changing neutral current (FCNC) process and is strongly suppressed in the standard model (SM). Its branching ratio is predicted to be $(2.43 \pm 0.39) \times 10^{-11}$ [1] in the SM, where the theoretical uncertainty is reduced to be small. Since the contribution of new particles to the loop diagram can change the decay rate drastically, this process is an excellent probe for the physics beyond the SM.

Due to the isospin symmetry, an upper limit for the branching ratio $\text{Br}(K_L \rightarrow \pi^0 \nu \bar{\nu})$ can be set from the $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ experimental limit. By using the latest result from the BNL E787 and E949 experiments[2], we obtain

$$\text{Br}(K_L \rightarrow \pi^0 \nu \bar{\nu}) < 1.4 \times 10^{-9}. \quad (1)$$

This indirect limit is called "Grossman-Nir bound"[3], and an experiment with a higher sensitivity than this means to search physics beyond the SM. On the other hand, the current experimental limit by the direct search is given as 2.6×10^{-8} (90%C.L.) by KEK E391a experiment[4], which is higher than the above limit by one order of magnitude.

The K^OTO experiment is the successor of E391a to search for this decay using an intense proton beam of Japan Accelerator Research Complex(J-PARC). The same experimental techniques are used with lots of improvements. The ultimate goal is to achieve the SM sensitivity, and the first physics data taking will be performed in 2013, where a better sensitivity than the Grossman-Nir bound is expected.

2 signal and background

The K^0 TO experiment is performed in the Hadron Experimental Facility of J-PARC using the 30GeV slowly-extracted proton beam. The primary proton beam hits the production target (nickel, platinum or gold; according to the beam power) and the narrow neutral beam is obtained from the secondary particles with the beamline consisting of collimators and a sweeping magnet. At the downstream of the beamline, the detector is placed to observe the K_L decay from the neutral beam.

Since it is not possible to tag the incident K_L and detect outgoing neutrinos, a single π^0 is the only visible particle in this decay process. Thus, we identify $K_L \rightarrow \pi^0 \nu \bar{\nu}$ events where only an isolated π^0 exists; two photons from π^0 are detected by an electromagnetic calorimeter and no visible energy in the "veto detectors" which surround the whole decay region.

There are two types of background : the K_L -induced one and the neutron-induced one. The former is due to detector inefficiency. When extra particles from K_L are not detected, such events can be regarded as signals. Since $K_L \rightarrow \pi^0 \pi^0$ decay has a similar topology to the signal event and a small number of extra particle (two photons from the additional π^0), this is the most serious background in the K^0 TO experiment. The $\text{Ke}3(K_L \rightarrow e \pi \nu)$ and $\text{K}\mu 3(K_L \rightarrow \mu \pi \nu)$ decays, in which two oppositely charged particles are emitted, have a large branching ratio and can fake as signals when both charged particles are not identified.

The latter one is due to the π^0 production by neutrons in the beam halo. When they hit materials around beam halo such as detector itself, π^0 or η can be generated. These events have two photons in the final state when no other particles produced or detected, and make backgrounds.

3 charged-veto detector

The K^0 TO electromagnetic calorimeter, whose diameter is 2m, consists of 2,716 undoped CsI crystals. The whole surface is covered by "Charged Veto" detector (CV), and a cluster of hit crystals without any output in CV is identified as a γ . When the CV fails to detect charge particles entering the calorimeter, they are misidentified as a photon, and can make background. Thus the inefficiency for charged particles must be suppressed to a low level for the wide region. On the other hand, since the detector itself can be a source of π^0 production by neutrons in the beam halo, the amount of materials should also be small.

To satisfy both requirements, we use 3mm-thick plastic scintillators (Saint-Gobain BC404) with wavelength shifting fiber (Kuraray Y11). Multi Pixel Photon Counters (MPPCs) by Hamamatsu are coupled to the both ends of fibers. The long attenuation length of the wavelength shifting fibers and high photon detection efficiency of MPPC enables us to get large light yield over the wide range, while the amount of materials is kept as small as possible.

The detector consists of two planes separated by 25cm each other. The front(rear) plane contains 48(44) modules, each of which is the combination of a scintillator strip, wavelength shifting fibers and MPPCs. The layout of the scintillator strips and the design of a module are shown in Fig.1. There are 7 U-shaped

grooves to set fibers with 1cm interval in a strip, and wavelength shifting fibers are set in each groove. Both sides of the strips where the neighboring strips come have an angle of 30° to the beam direction to eliminate the gaps between strips.

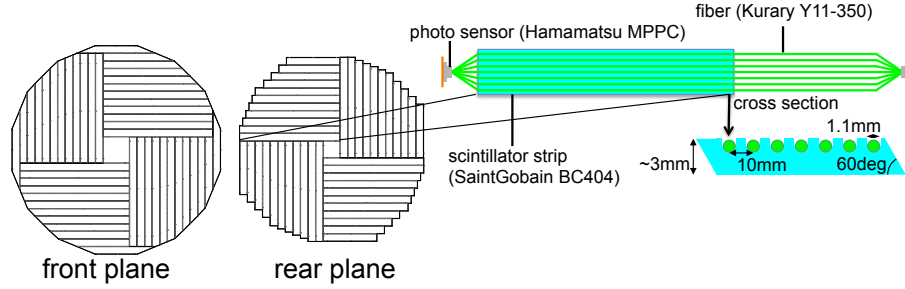


Figure 1. Layouts of modules in each plane(left) ;design of a module(right).

4 module production and construction

The scintillator strips for CV was cut from cast sheet with the size of $60\text{cm} \times 100\text{cm}$. The effect due to the non-uniformity of the scintillator thickness was studied by a Monte Carlo simulation, and the thickness of all sheets were measured. The path length of a particle in a scintillator is so short that the inefficiency due to photon statistics can increase drastically in a region where the grooves is too deep or thickness of a scintillator is too thin. As a result of a simulation, we found that the minimum thickness under grooves should be larger than 1.8mm to reduce the inefficiency less than 10^{-3} . The thickness for all cast sheet was measured using a laser displacement sensor. The maps of the measured thickness for each sheet was used to determine the thickness under grooves and the module assignment. Here regions thinner than 2.75mm was avoided in order to keep the thickness under grooves and not to make the grooves too shallow.

For the effective fabrication of the modules and the uniformity of quality among modules, an automatic gluing system shown in Fig.2 was developed to glue the grooved scintillator and the wavelength shifting fibers. Optical cement(EJ500) with lowered viscosity was used, where the mixture ratio is changed to resin:hardener=3.6:1.4 in weight from 4:1 in nominal to fit the system. The quantity of glue to apply was controlled by adjusting the stage speed. After the fabrication, the position dependence of light yield was inspected for each module by using a ^{90}Sr β ray source. It was confirmed that the enough light yield was achieved for all the modules in all the position.

These modules were shipped to J-PARC and the assembly was done. The support structure consisted of an aluminum frame with hexadecagon shape and the carbon fiber reinforced plastic(CFRP) plate. Each module was mounted on the CRRP plate and the readout electronics is equipped on the aluminum frame. Fig.3 is the photo of the construction.

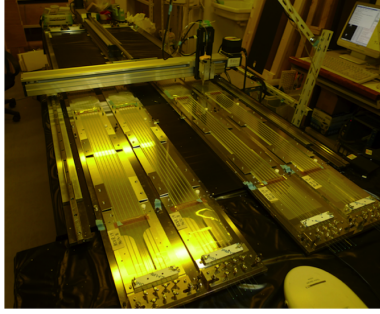


Figure 2. Photo of the fiber gluing system. A syringe containing the glue was mounted on electrical stages and its ejection was controlled by the dispenser synchronized with the stages. 4 modules with identical shape can be glued at the same time.



Figure 3. Photo in combining the two planes after the assembly of each plane.

5 performance test with K^0 TO neutral beam

The CV detector was installed to the K^0 TO experimental area and its performance was tested using two charged particles from K_L decay. A series of drift chambers were placed in front of CV, and the events with two charged particle are triggered by the scintillator hodoscope located in the downstream of CV. Signals from MPPCs were read by the same 125MHz FADC modules with Bessel filters which are used in the readout of the CsI calorimeter.

The one photoelectron gain of all MPPCs were monitored by the calibration system with blue LEDs. Fig.4 shows an example of waveform recorded by FADC. The sum of 25 samples around the signal timing was used to evaluate the output for each channel, and the output corresponding to the one-photoelectron pulse was stable within $\pm 3\%$ over 5 days.

The position dependence of light yield and timing resolution was evaluated for each module by using the hit position of the charged particles obtained by drift chambers. The light yield was defined as the integral, calculated with the same method described above, normalized by the one photoelectron output, and the timing resolution was estimated as the σ of gaussian fit for the distribution of the hit timing difference between two hits in the same module. The result is shown in Fig.5. For the most region, a higher light yield than 60 photoelectron and a timing resolution better than 3ns was achieved, which satisfied the requirement of the K^0 TO experiment to suppress the background the accidental loss enough.

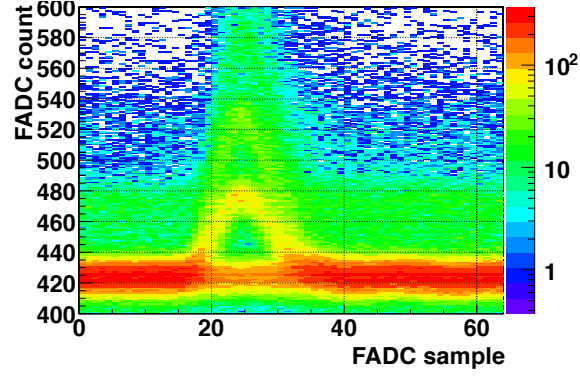


Figure 4. An example of waveform data for one photoelectron calibration run using LED. 64 samples were recorded for each event and LED trigger events are overlaid as a two-dimension histogram in this figure. Pedestal events and one photoelectron events are clearly separated.

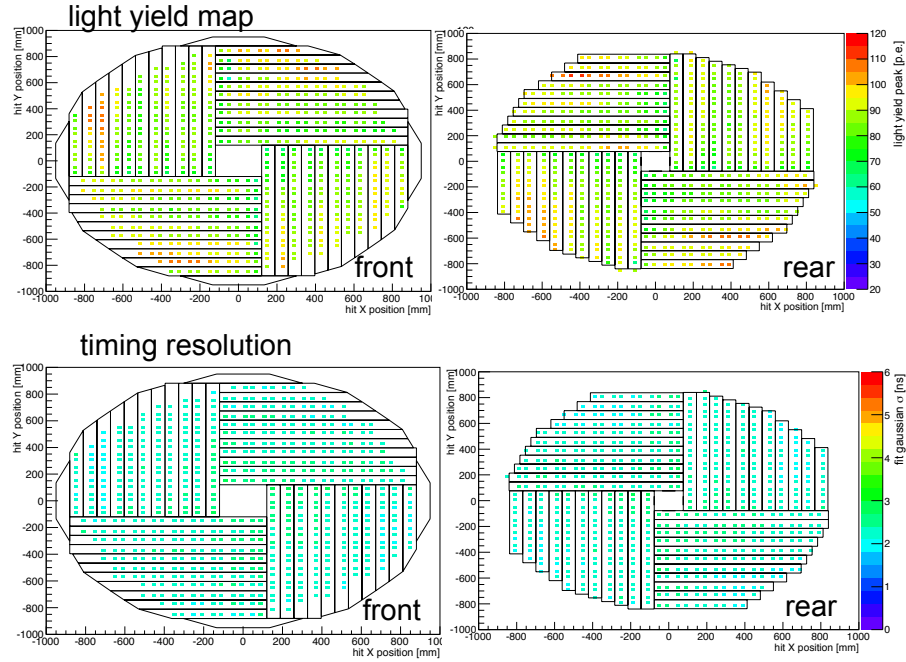


Figure 5. Measured position dependence of the light yield(top) and the timing resolution(bottom) for each plane.

6 summary & prospect

A charged-paritcle veto detector was successfully constructed to study the CP-violating rare decay $K_L \rightarrow \pi^0 \nu \bar{\nu}$ in J-PARC K^OTO experiment. Its performance was tested using K_L decay particle in the neutral K_L beam line. It was confirmed that the detector has an enough light yield and a goal timing resolution to active the SM sensitivity. The construction of whole K^OTO detector is in progress and the first physics run is schedules in 2013.

References

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